**T05D05 – 5.3 Hess’s Law of Summation**

Name …………………………………………………………..

Hess’ law is also called Hess’ Law of Summation as you are adding reactions together in order to come up with the reaction your really want. This is done for several reasons. One is if you do not have a thermodynamics table of enthalpies, and another is if the reaction will not go to completion as it is written, and so I am unable to do the reaction in the lab.

Hess’ Law states that it makes no difference whether I do the reaction in a single step or a series of steps the enthalpy must be the same value. [This is the 3rd rule of Thermochemistry]

Let me illustrate with two examples.

1st example:

I want to calculate the enthalpy change for the following reaction:

C2H4 (g) + H2O (l) 🡪 C2H5OH (l)

and I am given the following reactions

C2H5OH (l) + 3 O2 (g) 🡪 3 H2O (l) + 2 CO2 (g) ∆Ho  = -1367 kJ

C2H4 (g) + 3 O2 (g) 🡪 2 CO2 (g) + 2 H2O (l) ∆Ho = -1411 kJ

The first thing I want to do is to determine what I must do. The first reaction I am given has C2H5OH as a reactant, and I want it as a product therefore I will flip the first reaction and when I do that I must change the sign of the enthalpy +1367 kJ instead of -1367 kJ.

Next I notice that the second reaction has C2H4 as a reactant so I will keep that reaction the way it is.

Now I have

3 H2O (l) + 2 CO2 (g) 🡪 C2H5OH (l) + 3 O2 (g) ∆Ho  = +1367 kJ

C2H4 (g) + 3 O2 (g) 🡪 2 CO2 (g) + 2 H2O (l) ∆Ho = -1411 kJ

Now I can add the two equations up (and hopefully they will be the equation at the top that I wanted to get).

When I add them up the two equations (just like adding simultaneous equations in math) the three oxygen’s (3 O2) can be subtracted away (reactant on one side and product on the other side in equal numbers), and the two carbon dioxides (2 CO2) can also be subtracted. Two of the waters also can be eliminated (3 H2O’s on the reactant side and 2 H2O’s on the product side).

So what I get is 🡪 C2H4 (g) + H2O (l) 🡪 C2H5OH (l)

This is the equation I wanted so now I add the two enthalpy values, and I get -44 kJ (+1367 kJ and a -1411 kJ), and I add this component to the above and make it a thermo chemical equation.

C2H4 (g) + H2O (l) 🡪 C2H5OH (l) ∆Ho = -44 kJ

If I check this with thermo tables, you will get an answer very close to if not exactly the one listed above.

That is the beauty of Hess’ law which states that if a reaction can be described by a series of steps, the ∆H (change in enthalpy) for the reaction is simply the sum of the enthalpies for each of the steps.

If I did the above equation in three steps or more instead of two the ∆H for the reaction would still be the same answer.

Let’s try another one:

Given the following data:

H2 (g) + Cl2 (g) 🡪 2 HCl (g) ∆Ho = -185 kJ

2 H2 (g) + O2 (g) 🡪 2 H2O (g) ∆Ho = -483.7 kJ

I want to calculate ∆Ho for the reaction

4 HCl (g) + O2 (g) 🡪 2 Cl2 (g) + 2 H2O (g)

The first thing I should notice is that the first equation above has to be flipped and also doubled because HCl in the reaction I WANT has a coefficient of 4 in front of it. The second equation will be left alone. Do you see why? Oxygen is needed as a reactant and water is needed as a product. I am not going to double it as I only want 1 oxygen, and 2 waters.

So this is what I get:

4 HCl (g) 🡪 2 H2 (g) + 2 Cl2 (g) ΔHo = + 370 kJ

I have doubled the equation, and flipped it so therefore the ΔH value must also be doubled, and the sign must be change (I flipped the equation)

Now the second equation as written:

2 H2 (g) + O2 (g) 🡪 2 H2O (g) ∆Ho = -483.7 kJ

Now I add the two equations and get:

4 HCl (g) + O2 (g) 🡪 2 Cl2 (g) + 2 H2O (g)

This is the equation I wanted, and now all I do is add the two enthalpies (ΔHo’s) and I get -113.7 kJ (+370 kJ – 483.7 kJ)

These take practice and patience. You have to plan before you act. You must determine which if any of the equations have to be flipped, and which one or ones have to be multiplied (or even divided). Once you get the equations set up correctly all you do is add up the enthalpies (ΔHo’s).

Now you try one:

Given the following data:

C2H2 (g) + 5/2 O2 (g) 🡪 2 CO2 (g) + H2O (l) ∆Ho = -1300 kJ

C (s) + O2 (g) 🡪 CO2 (g) ∆Ho = -394 kJ

H2 (g) + ½ O2 (g) 🡪 H2O (l) ∆Ho = -286 kJ

Calculate ∆Ho for the reaction:

2 C (s) + H2 (g) 🡪 C2H2 (g)

Three equations are more difficult than two but try it in the space provided.

When finished you should get an answer close to +227 kJ. If you got that answer good job. If not, try harder. Persistence pays off. These take practice. The only way you become good at anything is with practice.

Remember you may have to double or triple an equation and also may have to flip the same equation. Take your time.

Some are easy and some are very difficult. They all take patience. Here are some more to try:

1. Calculate the standard enthalpy change for the reaction

2 Al (s) + Fe2O3 (s) 🡪 2 Fe (s) + Al2O3 (s)

given that:

2 Al (s) + 3/2 O2 (g) 🡪 Al2O3 (s) ΔHo = -1601 kJ

2 Fe (s) + 3/2 O2 (g) 🡪 Fe2O3 (s) ΔHo = -821 kJ

### 2. Calculate the standard enthalpy change (kJ) for the following reaction of nitrogen dioxide with water:

### 3 NO2(g) + H2O(l) 🡪 2 HNO3(aq) + NO(g)

2 NO(g) + O2(g) 🡪 2 NO2(g) ∆Ho = -114 kJ  
2 N2(g) + 5 O2(g) + 2 H2O(l) 🡪 4 HNO3(aq) ∆Ho = -255 kJ  
N2(g) + O2(g) 🡪 2 NO(g) ∆Ho = +181 kJ

### 3. Given the following equations and ∆Ho values, determine the heat of reaction (kJ) at 298 K for the reaction:

### 2 NF3(g) + Cu(s) 🡪N2F4(g) + CuF2(s)

2 NF3(g) + 2 NO(g) 🡪 N2F4(g) + 2 NOF(g) ∆Ho = -82.9 kJ  
NO(g) + 1/2 F2(g) 🡪 NOF(g) ∆Ho = -156.9 kJ  
Cu(s) + F2(g) 🡪 CuF2(g) ∆Ho = -531.0 kJ

### 4. Given the following equations and ∆Ho values, determine the heat of reaction (kJ) at 298 K for the reaction:

### N2H4(l) + O2(g) 🡪N2(g) + 2 H2O(l)

2 NH3(g) + 3 N2O(g) 🡪 4 N2(g) + 3 H2O(l) ∆Ho  = -1013 kJ  
N2O(g) + 3 H2(g) 🡪 N2H4(l) + H2O(l) ∆Ho  = -317 kJ  
2 NH3(g) + 1/2 O2(g) 🡪 N2H4(l) + H2O(l) ∆Ho  = -142.9 kJ  
H2(g) + 1/2 O2(g) 🡪 H2O(l) ∆Ho  = -285.8 kJ

### 5. Determine ∆Ho /kJ for the following reaction using the listed enthalpies of reaction:

### C2H4(g) + Cl2(g) 🡪C2H4Cl2(l)

2 Cl2(g) + 2 H2O(l) 🡪 4 HCl(g) + O2(g) ∆Ho  = +202.5 kJ  
2 HCl(g) + C2H4(g) + 1/2 O2(g) 🡪 C2H4Cl2(l) + H2O(l) ∆Ho  = -319.6 kJ  
1/2 H2(g) + 1/2 Cl2(g) 🡪 HCl(g) ∆Ho  = -92.3 kJ  
H2(g) + 1/2 O2(g) 🡪 H2O(l) ∆Ho  = -285.8 kJ

Worksheet modified from Al Olsen – Towson High School, MD